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I, (Name and address of applicant, and in case of body corporate-place of incorporation)

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(באנגלית) (English)
Method and system for determining temperature and/or emissivity function of objects by remote sensing

מבקש בזאת כי ינתן לי עליה פטנט
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היום 19 בחודש November שנת 1997
This 19 of November of the year 1997

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Method and system for determining temperature and/or emissivity function of objects by remote sensing

Engineering Division
Commercial Aircraft Group

מרכז הנדסה חטיבת כלי טיס אזרחיים

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METHOD AND SYSTEM FOR DETERMINING TEMPERATURE AND/OR EMISSIVITY FUNCTION OF OBJECTS BY REMOTE SENSING

FIELD OF THE INVENTION

The present invention relates to a method and a system for remotely determining temperature and emissivity parameters of objects by multi-spectral measurements in the infrared spectrum range, with particular application to heated non-transparent samples and materials.

BACKGROUND OF THE INVENTION

In many branches of industry, for example in metallurgy or in manufacture of semiconductor devices samples and materials are subjected to various operations at high temperature.

Determining temperature of such objects during the manufacturing process presents a very important task, which is rather difficult to perform for the following reasons:

- it is impossible to perform direct (contact) temperature measurements, so the temperature determination is usually performed remotely by acquiring data on the infrared radiation of the sample and further processing this data,

- in the mathematical processing of the remotely obtained data many parameters intrinsic to the material of interest must be used (such as its thermal emissivity, etc.), which are usually unknown and cannot be directly measured.

IL patent application No. 113925 filed on April 13, 1995 by the present Applicant describes a method and system for determining inhomogeneities and imperfections in the vicinity of the earth's surface by remote sensing. To this purpose, there is suggested a method of remotely determining the temperature of the earth's surface by acquiring electromagnetic radiation data from a selected region thereof in one or more pairs of spectral bands being close to one another, and further deriving a temperature value from said data using a system of equations. Each of the equations describes the electromagnetic radiation that is emitted from the selected region in the chosen band, as a function of the temperature and the respective emissivity of the earth. In the suggested method, emissivity values of the earth in the chosen close spectral bands are assumed to be equal, so as to reduce the number of unknowns in the system of equations and render it solvable.

It is acknowledged in the prior art, that emissivity of various materials may noticeably depend on wavelength of the emitted radiation and temperature of the sample.

For example, US 4,659,234 describes a method of emissivity error correcting for a radiation thermometer, where the temperature is determined based on two measurements of radiated infrared energy at two closely adjoining wavelengths, and the result is corrected using one single measurement. While the method is aimed to solve the problem of determining the randomly changing value of emissivity of heated metal objects, it does not take into consideration any dependence of emissivity on the radiation wavelength and/or on temperature of the object. Such an approach renders the method inaccurate.

US 5,132,922 describes an emissivity-independent multi-wavelength pyrometer operating according to a method using a least-squares-based multi-wavelength pyrometry technique and a theoretical function for the dependence of the radiance on the wavelength. However, in this method the emissivity/wavelength function is considered to be the same in all spectral bands, which leads to a significant reduction in the accuracy of the determined

temperature, especially for heated non-transparent materials and samples which undergo heating.

Moreover, in all the above-described methods it is assumed that the temperature of an object does not change during the measurements session, in other words - none of the methods appears to suggest a way of real time non-contact temperature determination. These methods are therefore unsuitable for monitoring the thermal condition of samples or materials that undergo heating, cooling or any temperature fluctuations, for example during a technological process to which the object is subjected.

SUMMARY OF THE INVENTION

It is therefore a principal purpose of the present invention to provide an accurate method of remotely determining temperature of objects, being, in particular, applicable to heated objects and objects which undergo heating, cooling or any temperature fluctuations.

Another purpose of the invention is to provide a method for determining an emissivity function of these objects. Yet another objective of the invention is the provision of a system for implementing at least one of the above-mentioned methods.

The term "object" used herein with reference to temperature measurements or determining the emissivity function should be understood as meaning any material in a solid, liquid or gaseous state, from which it is possible to remotely receive emitted infrared radiation (for example - solid samples, oil spots on water, clouds, etc).

The above purpose can be achieved by providing a method of remotely determining temperature of an object, the method comprising:

- acquiring electromagnetic radiation data from the object in N spectral bands in the infrared spectral range,
- deriving a temperature value from said data using a system of equations, each describing the electromagnetic radiation that is emitted from

the object in a respective one of said bands as a function of the temperature and the respective emissivity of the object;

the method being characterized in that,

- said electromagnetic radiation is successively measured M times in each of said N spectral bands simultaneously, thus obtaining N*M readings,
- a system of N*M equations is formed, comprising N*M readings of the electromagnetic radiation and at least N+M unknowns which include M values of the object's temperature corresponding to said respective M measurements of the electromagnetic radiation, and at least N values of emissivity for said respective N spectral bands, and
- solving said system of N*M equations, thus deriving temperature of the object at any one of the M successive moments of said electromagnetic radiation measurement.

The above-defined new method is based on the following assumptions:

1. Emissivity of the object in each one of the N spectral bands is a predetermined function of temperature having parameters which are constant during all the M measurements of the electromagnetic radiation performed in this band; in the simplest case this function is just a constant for each specific spectral band, so the number of unknowns will be equal N+M.
2. During each specific measurement of the electromagnetic radiation, the temperature of the sample is assumed to be constant (i.e. its change is considered negligible), regardless in which spectral band the specific measurement is performed.

In practice, i.e. when digital computing technology is used for controlling the process of measurements and processing the obtained data, each of said M multi-spectral measurements of the electromagnetic radiation (i.e. each of said M*N readings thereof) is digitized and stored in a computer memory for further computerized processing, said processing comprises substituting the digitized M*N readings of the electromagnetic radiation into the M*N equations, and solving thereof.

According to one specific version of the method the equations are integral ones, for example Fredholm equations relating to emissivity.

It should be emphasized, that the above-defined method easily provides sufficiently accurate temperature values both in cases when emissivity of the sample essentially varies from one spectral band to another (either due to dispersion between these bands, or due to specific physical properties of the object), and in cases when the emissivity is essentially uniform throughout the spectrum.

In addition, the succession of thus obtained temperature values may be used for real-time monitoring and controlling of the object's thermal condition, for example during a technological process to which the object is subjected and where it undergoes any temperature fluctuations (for example, heating, cooling, automatic maintaining a required temperature, etc).

It is well known, that in a wide range of temperatures (i.e. those between the room temperature and 1,500^{O}C) emissivity of some real materials, such as semiconductor samples, varies not only from one spectral band to another, but also depends on the temperature of the sample. In other words, the simplest case of assumption 1 mentioned above is not applicable to such objects, and, when the temperature of heated non-transparent objects must be determined, the method where only N+M unknowns are sought for will not be sufficiently accurate. It means, that if the sample emissivity is considered to be independent of temperature while the sample undergoes any thermal treatment, this assumption will be a source of essential errors in calculations of the temperature.

Having assumed that emissivity of the heated sample is a known mathematical function of temperature and wavelength with unknown parameters, the present invention introduces such parameters as unknowns into the above-mentioned system of equations, in order to obtain values of the parameters by solving the system.

More particularly, each of the M*N equations describes the electromagnetic radiation that is emitted from the object in one of the bands

as a function of the temperature and the respective emissivity of the object, the emissivity, in turn, being a known function of temperature, wavelength and a known number of unknown parameters; said parameters being introduced as additional unknowns into said system of equations for further obtaining their values upon solving the system.

In one example, the mentioned known function may be represented as a sum of a known number of terms of two other functions, a first of which is dependent only on temperature and a known number of unknown parameters, and a second - only on wavelength.

According to another example, this known function may be represented by a polynomial expansion having K unknown coefficients, said coefficients being introduced into the system of equations as the unknown parameters to be determined upon solving said system.

If the emissivity variable in each of the above mentioned equations is represented as a polynomial function having K unknown coefficients, the system of the equations will become more complex. Thus, though the number of equations N*M is unchanged, the number of unknowns in the system will increase and become equal to M + K*N, where K is the number of polynomial coefficients of the emissivity/temperature function in each of the N spectral bands. However, if the number of the polynomial coefficients is different in different spectral bands (which case is more general and more correct from the physical point of view), the number of unknowns in the system will be

$$M + (K_{\Delta 1} + K_{\Delta 2} + \ldots K_{\Delta N}),$$

where $K_{\Delta 1}, \ldots K_{\Delta N}$ are numbers of the polynomial coefficients of the emissivity/temperature function in each of the spectral bands, respectively.

In practical applications, where the electromagnetic measurements are performed and processed by the aid of a computer, the number of electromagnetic radiation measurements M and the number of spectral bands N may be as great as is wished. For example, in industrial conditions during a relevant technological process up to 2,000 measurements may be performed

in a short period of time, each measurement taking from 1 to 10 msec. On the other hand, the number K of polynomial coefficients in the function emissivity/temperature usually does not exceed 3. Owing to that the system of such equations is solvable, since

$$N^*M >> M + K^*N, \quad \text{or}$$

$$N^*M >> M + (K_{\Delta 1} + K_{\Delta 2} + ...K_{\Delta N}).$$

The most effective application of the above described modified method is for non-contact temperature measurement of heated non-transparent objects (or objects undergoing heating, cooling or any other temperature fluctuations), for example of semiconductor materials and samples during their manufacture.

It should be emphasized that, since values (parameters) of the emissivity function are solutions of said system of M*N equations, as are the temperature values, the above-disclosed method of remotely measuring temperature of an object also constitutes a method of determining the emissivity function of the object.

In other words, there is provided a method of remotely determining emissivity function of an object, the method comprising

- acquiring electromagnetic radiation data from the object in N spectral bands in the infrared spectrum by successively measuring it M times in each of the N spectral bands simultaneously, thus obtaining N*M readings,

- forming a system of N*M equations, each describing the electromagnetic radiation that is emitted from the object in one of said bands as a function of the temperature and the respective emissivity of the object; the system of N*M equations comprising N*M readings of the electromagnetic radiation and at least N+M unknowns which include M values of the object's temperature corresponding to said respective M measurements of the electromagnetic radiation, and at least N values of emissivity, each for a respective one of said N spectral bands,

- solving said system of N*M equations, thus deriving a plurality of unknowns comprising at least N values of the object's emissivity corresponding to the N spectral bands, and

- forming the emissivity function of the object using the obtained plurality of unknowns.

It is to be noted, that the problem of determining the emissivity function of real objects is one of important problems in many industrial applications.

In accordance with a further aspect of the invention, there is provided a system for remotely determining temperature and/or emissivity function of an object, said system comprising:

sensing means for acquiring electromagnetic radiation data from the object M times in real time, each in respect of N spectral bands of the infrared spectral range simultaneously, thus obtaining N*M real time readings of the electromagnetic radiation;

means for recording and storing said N*M readings in digital form;

computational means coupled to the storing means, for processing said N*M readings of the electromagnetic radiation as a system of N*M equations comprising M unknown values of temperature and at least N unknown values of emissivity function of the object; and

display means coupled to the computational means for displaying one or more of said unknowns obtained upon solving said system of equations.

Finally, it will be appreciated that the above described methods and system for remotely determining temperature and/or emissivity function of an object may be utilized for deriving temperature and/or emissivity descriptive maps of the object.

To this end, the object is divided into a plurality of representative segments, and each segment is to be investigated according to the above-suggested technique. The processed data on the temperature and/or emissivity function associated with each specific segment of the object can then be used for forming a corresponding pixel of the respective descriptive map.

The system adapted for the mapping must additionally be provided with scanning means for applying the above-described method to a plurality of the representative segments of the object, and also with means for deriving at least one of said descriptive maps based on data processed by said computational means.

According to one embodiment of the system, the scanning means comprises a spatial optical filter divided into a number of sites for acquiring the electromagnetic radiation from the plurality of respectively located segments of the object; each site having N zones responsible for splitting the radiation acquired by the site into N spectral bands.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and see how the same may be carried out in practice, preferred embodiments will now be described by way of non-limiting examples only, with reference to the accompanying drawings, in which:

Figs. 1a and 1b present a flow-chart showing the principal steps in a method of non-contact temperature measurement according to the invention;

Fig. 2 is a flow-chart of a modified method based on that illustrated in Fig. 1b;

Fig. 3 is a block-diagram showing functionally a system for implementing the inventive method; and

Figs. 4a and 4b are schematic plan views of two embodiments of the filter shown in Fig. 3.

DETAILED DESCRIPTION OF THE INVENTION

Before relating to the drawings, some basic terms and indications of constants and variables are to be introduced, which will be used further below in the examples of the inventive method.

In general, the method of the invention is applicable to objects consisting of materials which are homogenous from the point of view of radiation parameters.

Radiation of the object includes three components:

$$\begin{aligned} W &= W1 + W2 + W3 \\ W1 &= \varepsilon * W_B \\ W2 &= R * Y \\ W3 &= tr * G \end{aligned} \tag{1}$$

where:

W - total radiation of the object

W1 - radiation emitted by the object

W2 - radiation reflected by the object

W3 - radiation transmitted by the object through its body

ε - emissivity coefficient of the object

R - reflectance coefficient

tr - transmittance coefficient

$(1 = tr + R + \varepsilon)$

W_B - radiation of the black body having temperature equal to that of the object

G - radiation existing at the back side of the object

Y - background radiation arriving to the object.

For a non-transparent object (having tr = 0), which is heated to a relatively high temperature with respect to the ambient one, both W2 and W3 are equal 0.

In this case radiation W^i in the spectral band $\Delta_i = [\lambda_i, \lambda^i]$ can be represented by formula (2):

$$W^i = \int_{\lambda_i}^{\lambda^i} \varepsilon(\lambda,T) * B(\lambda,T) * d\lambda \tag{2}$$

where:

T = temperature of the object.

$B(\lambda,T)$ = the Planck function of thermal radiation of the black body.

For determining intensity of infrared radiation emitted from the object, a reference body can be selected, whose radiation/temperature dependencies in each predetermined spectral band are known.

A radiometer can detect radiation of the object in several spectral bands. In a specific spectral band, the received radiation V^i may be represented by an integral equation (3):

$$V^i = \int_{\lambda_i}^{\lambda^i} \varphi^i(\lambda) * \varepsilon(\lambda,T) * B(\lambda,T) * d\lambda \qquad (3)$$

where

$\varphi^i(\lambda)$ = function dependent on the radiometer's parameters for a specific band "i" and on transmitting properties of the atmosphere.

If the radiation measurements are performed M times (1...j...M) (say, at M different unknown temperatures T_j), each time in N spectral bands (1...i...N) simultaneously (see blocks 1, 2, 3 in Fig. 1a), the following system of N*M equations may be built and solved:

$$V^{ij} \equiv V^i_{T_j} = \int_{\lambda_i}^{\lambda^i} \varphi^i(\lambda) * \varepsilon(\lambda,T_j) * B(\lambda,T_j) * d\lambda \qquad (4)$$

Solution of the above system of equations will yield M values of temperature ($T_1..T_j..T_M$) and N values of emissivities ($\varepsilon_1..\varepsilon_i..\varepsilon_N$), as can be seen from both the equations (4) and Figs 1a, 1b (blocks 4, 5, and 6).

Fig. 2 illustrates a modified final portion of the flow-chart, which, together with the flow-chart diagram shown in Fig. 1a will form an algorithm suitable for cases when the object's emissivity depends both on wavelength and temperature. The system of equations processed in block 7 of the modified algorithm is more complex than system (4) (see also block 5 in Fig. 1b), in that in each of the N*M equations, dependence of the emissivity variable "ε" on temperature of the sample is taken into consideration.

For example, the emissivity function of the heated object in spectral channel "i" can be represented as follows:

$$\varepsilon^i(\lambda, T) = \sum_{k=1}^{K} E^i_k(\lambda) * S^i_k(T) \qquad (\lambda \in \Delta_i) \tag{5}$$

where: $S_k^i(T)$ - is a function reflecting dependency of the emissivity on temperature;

$E_k^i(\lambda)$ - is a function reflecting dependency of the emissivity on wavelength.

Behavior of the functions $S_k^i(T)$ and $E_k^i(\lambda)$ is assumed to be known (i.e. the functions are selected in advance); parameters of the function $E_k^i(\lambda)$ are also assumed to be known.

K - is the preselected number of terms $S_k^i(T)*E_k^i(\lambda)$

Based on the above, the following system of N*M equations may be built and solved:

$$V^{ij} = \sum_{k=1}^{K} S_k^i(T_j) * R_k^i(T_j) \qquad (6)$$

where:

$$R_k^i\ (Tj) = \int_{\lambda_i}^{\lambda^i} E_k^i(\lambda) * \varphi^i(\lambda) * B(\lambda, T_j) * d\lambda \qquad (7)$$

is integral of the preselected functions E, B and φ.

Solving the system (6) permits derivation of M values of the sample temperature, and N*K parameters for all functions $S_k^i(T_j)$.

In yet another example, the above-mentioned emissivity function $S_k^i(T_j)$ may be expanded into a polynomial series, and the equation (5) will acquire the following form:

$$\varepsilon(\lambda, T) = \sum_{\substack{k=1 \\ (\lambda \in \Delta_i)}}^{K} \sum_{q=1}^{Q} b_{kq}^i * P_q^i(T_j) * E_k^i(\lambda) \qquad (8)$$

where:

b^i_{kq} = parameters of function $S_k^i(T_j)$ in the "i" spectral band;

$P^i_q(T_j)$ = polynomial of a preselected form and with preselected coefficients;

$(b^i_{kq} * P^i_q(T_j))$ = forms $S_k^i(T_j)$;

Q - number of polynomial coefficients.

The system of equations in this case will be as follows:

where:

$$V^{ij}=\sum_{k=1}^{K}\sum_{q}^{Q} b_{kq}^{i} * P_{k}^{i}(T_j) * R_{kq}^{i}(T_j) \qquad (9)$$

$i = \{1,N\}$, $j = \{1,M\}$, $k =\{1,K\}$, $q = \{1,Q\}$.

Solution of the above system (9) of N*M equations will give M unknown values of temperature, and N*K*Q parameters b_{kq}^{i} of the function $S_k^{i}(T_j)$ (for the case when in each spectral band there is one and the same number of the parameters).

It should be emphasized that, knowing the above mentioned parameters and the functions $E_k^{i}(\lambda)$, one can exactly define the wavelength and temperature dependent function of emissivity.

The above system of equations is linear for parameters b_{kq}^{i}, and non-linear for values of temperature T_j.

Accuracy of the temperature calculations depends on the following factors:

- number N of the spectral bands, and on specific selection of the bands,
- number M of the "temperature" (i.e. electromagnetic radiation) measurements,
- quality of synchronizing of the "temperature" measurements in the N spectral bands, i.e. performing thereof substantially simultaneously,
- technical parameters of radiometers and accuracy of the radiometric measurements,
- accuracy of the mathematical model.

Based on the above description and examples, the method of remotely measuring temperature of an object suggested in the present application represents also a method of determining emissivity function of the object.

Fig. 3 is a block-diagram showing functionally a system for implementing the inventive method.

The system for remotely determining temperature and/or emissivity function of an object comprises:

sensing means including an optics 12, an optical filter 14 and a detector 16 for acquiring electromagnetic radiation data from the object M times in real time, each in respect of N spectral bands of the infrared spectrum simultaneously, thus obtaining N*M real time readings of the electromagnetic radiation;

storage means (not shown) coupled to the sensing means, for recording and storing said N*M readings in digital form;

a processing unit 18 integrally coupled to the storage means, for processing said N*M readings of the electromagnetic radiation as a system of N*M equations comprising M unknown values of temperature and at least N unknown values of emissivity function of the object; and

a display 22 coupled to the processing unit 18 for displaying one or more of said unknowns obtained upon solving said system of equations.

A heated object 10 emits infrared radiation on to the optics 12 via which it is transmitted to the multichannel spatial optical filter 14. The multichannel spatial filter 14 performs simultaneous splitting of spectral lines into N spectral bands. In Fig. 4a there is shown schematically a plan view 28 of the multichannel spatial filter which is designed to split the spectrum into N=12 spectral bands (channels) by 12 zones adapted to transmit radiation of different wavelengths. Practical implementation of the filter is not discussed in the framework of the present patent application. Intensities of the obtained N radiation portions are then detected by a detector 16 adapted for multichannel detection. N analogous readings of the electromagnetic radiation obtained by the detector 16 are converted into the digital form and transmitted to the processing unit 18 where they are stored for further processing.

All the above-described operations are synchronized by a control unit 20 of the processing unit 18, which generates M successive synchronizing

signals. Each of these M signals simultaneously activates the optics 12, multi-channel filter 14, detector 16 and processing unit 18 for performing and recording N measurements of the infrared radiation being effected substantially simultaneously in N spectral bands, respectively. M*N digitized readings of the infrared radiation emitted from the object 10 are thus obtained and processed in the unit 18 as a system of equations having at least M+N unknowns representing M values of temperature of the object and at least N parameters of its emissivity function. Values of the temperature (and/or of the emissivity), being solutions of these equations, are displayed by the display 22. If desired, the system can be adapted for deriving a temperature descriptive map of the object, as well as an emissivity descriptive map thereof. To this end, optional thermal mapping unit 24 and an emissivity mapping unit 26 are connected to the processing unit 18. For making the mapping operation possible, the filter 14 may have a structure shown in Fig. 4b.

Fig. 4b illustrates a plan view of a spatial filter 30 divided into a number of sites 32 for acquiring infrared radiation from a number of respectively located segments of the object (not shown). Each site has N=4 zones responsible for splitting the infrared radiation acquired by the site into four spectral bands. A plurality of the split radiation portions from all sites of the filter 30 may be then transmitted to a detector similar to that shown as 16 in Fig. 3, and further to a similar processing unit. The processing unit will process the stored digitized information so as to produce values of temperature and/or emissivity associated with every one of the sites 32 of the filter 30, for further composing a descriptive map of temperatures (emissivities) of the corresponding segments of the object.

Geometric shape and parameters of the spatial filter 30 may be selected according to each specific application.

CLAIMS:

1. A method of remotely determining temperature of an object, the method comprising

- acquiring electromagnetic radiation data from the object in N spectral bands in the infrared spectral range,

- deriving a temperature value from said data using a system of equations, each describing the electromagnetic radiation that is emitted from the object in a respective one of said bands as a function of the temperature and the respective emissivity of the object;

the method being characterized in that,

- said electromagnetic radiation is successively measured M times, in each of said N spectral bands simultaneously, thus obtaining N*M readings,

- a system of N*M equations is formed, comprising N*M readings of the electromagnetic radiation and at least N+M unknowns which include M values of the object's temperature corresponding to said respective M measurements of the electromagnetic radiation, and at least N values of emissivity for said respective N spectral bands, and

- solving said system of N*M equations, thus deriving a succession of M values of the object's temperature corresponding to the M successive moments of said electromagnetic radiation measurement.

2. A method of remotely determining emissivity function of an object, the method comprising

- acquiring electromagnetic radiation data from the object in N spectral bands in the infrared spectrum by successively measuring it M times, in each of said N spectral bands simultaneously, thus obtaining N*M readings,

- forming a system of N*M equations, each describing the electromagnetic radiation that is emitted from the object in one of said bands as a function of the temperature and the respective emissivity of the object; the system of equations comprising N*M readings of the electromagnetic radiation and at least N+M unknowns which include M values of the object's

temperature each corresponding to a respective one of said M measurements of the electromagnetic radiation, and at least N values of emissivity for said respective N spectral bands,

- solving said system of N*M equations, thus deriving a plurality of unknowns comprising at least N values of the object's emissivity corresponding to the N spectral bands, and

- forming the emissivity function of the object using the obtained plurality of unknowns.

3. The method according to Claim 1 or 2, wherein each reading obtained from said M measurements of the electromagnetic radiation is digitized and stored in a computer memory for further computerized processing, said processing comprising substituting the digitized M*N readings of the electromagnetic radiation into said M*N equations, and solving thereof.

4. The method according to any one of the preceding claims, wherein said equations are integral.

5. The method according to Claim 4, wherein said equations are Fredholm equations relating to emissivity.

6. The method according to claim 4 or 5, wherein each of said M*N equations describes the electromagnetic radiation that is emitted from the object in one of said bands as a function of the temperature and the respective emissivity of the object; the emissivity, in turn, being a known function of temperature, wavelength and a known number of unknown parameters; said parameters being introduced as additional unknowns into said system of equations, their values being obtained upon solving the system.

7. The method according to Claim 6, wherein said known function is a sum of a known number of terms of two other functions, a first of which being dependent only on temperature and a known number of unknown parameters, and a second being dependent only on wavelength.

8. The method according Claim 6, wherein said function is represented by a polynomial expansion having K unknown coefficients, said coefficients

being introduced into the system of equations as said unknown parameters to be determined upon solving the system.

9. A method for deriving a temperature and/or emissivity descriptive maps of an object, the method comprising the following steps:

- dividing the object into a plurality of representative segments,
- applying the method according to any one of the preceding claims to each of said segments, so as to derive respective temperature and/or emissivity values, and
- mapping each of the temperature and/or emissivity values to a respective pixel of said descriptive map.

10. The method according to any one of the preceding claims, specifically adapted for being applied to objects undergoing temperature fluctuations.

11. The method according to any one of the preceding claims, specifically adapted for the real-time monitoring and controlling of thermal condition of samples during their manufacture.

12. A system for remotely determining temperature and/or emissivity function of an object by the method according to any one of the preceding claims, said system comprising:

- sensing means for acquiring electromagnetic radiation data from the object M times in real time, each in respect of N spectral bands of the infrared spectrum simultaneously, thus obtaining N*M real time readings of the electromagnetic radiation;
- storage means coupled to the sensing means, for recording and storing said N*M readings in digital form;

processing means coupled to the storage means, for processing said N*M readings of the electromagnetic radiation as a system of N*M equations comprising M unknown values of temperature and at least N unknown values of emissivity function of the object; and

display means coupled to the processing means for displaying one or more of said unknowns obtained upon solving said system of equations.

13. The system according to Claim 12, further including map generation means for determining the temperature and/or emissivity values in respect of X representative segments of the object and mapping said values to X respective pixels of a temperature and/or emissivity descriptive map.

14. The system according to Claim 13, wherein map generation means comprises a spatial optical filter divided into a number of sites, each for acquiring the electromagnetic radiation from a respective one of said X segments of the object; each said site having N zones for splitting the radiation acquired by the site into N spectral bands.

For the Applicants,
DR. REINHOLD COHN AND PARTNERS
By:

104534.SPC.EL/be-19.11.1997

START

1

SIMULTANEOUS ACQUIRING N READINGS OF EM RADIATION FROM THE OBJECT AT A MOMENT T_1 IN N SPECTRAL BANDS $\Delta_1 \Delta_2 .. \Delta_i .. \Delta_N$, RESPECTIVELY, FOR DETERMINING A SOUGHT FOR TEMPERATURE T_1

DIGITIZING THE OBTAINED N READING

STORING THE DIGITIZED READINGS

2

SIMULTANEOUS ACQUIRING N READINGS OF EM RADIATION FROM THE OBJECT AT A MOMENT T_j IN N SPECTRAL BANDS $\Delta_1 \Delta_2 .. \Delta_i .. \Delta_N$, RESPECTIVELY, FOR DETERMINING A SOUGHT FOR TEMPERATURE T_j

DIGITIZING THE OBTAINED N READING

STORING THE DIGITIZED READINGS

3

SIMULTANEOUS ACQUIRING N READINGS OF EM RADIATION FROM THE OBJECT AT A MOMENT T_M IN N SPECTRAL BANDS $\Delta_1 \Delta_2 .. \Delta_i .. \Delta_N$, RESPECTIVELY, FOR DETERMINING A SOUGHT FOR TEMPERATURE T_M

DIGITIZING THE OBTAINED N READING

STORING THE DIGITIZED READINGS

4

SUBSTITUTING THE STORED N*M READINGS OF EM RADIATION INTO N*M INTEGRAL EQUATIONS AND FORMING A SYSTEM OF SAID EQUATIONS

1 to FIG. 1b or to FIG. 2

FIG. 1a

From FIG. 1a [1]

5

PROCESSING THE SYSTEM OF N*M EQUATIONS, IN EACH OF WHICH THE EM RADIATION VALUE V IN A PARTICULAR SPECTRAL BAND Δ_i IS A FUNCTION OF TEMPERATURE T AND EMISSIVITY ε OF THE SAMPLE

$$V^{i}_{T_j} = f\,(T_j\,,\,\varepsilon_i)$$

6

OBTAINING M SUCCESSIVE VALUES OF TEMPERATURE OF THE OBJECT

$(T_1 \ldots T_j \ldots T_M)$, AND

OBTAINING N VALUES OF EMISSIVITIES

$(\varepsilon_1 \ldots \varepsilon_i \ldots \varepsilon_N)$ FOR N SPECTRAL BANDS, RESPECTIVELY

FIG. 1b

From FIG. 1a 1

7

PROCESSING THE SYSTEM OF N*M EQUATIONS, IN EACH OF WHICH THE EM RADIATION VALUE V IN A PARTICULAR SPECTRAL BAND Δ_i IS REPRESENTED AS A FUNCTION OF TEMPERATURE T AND THE TEMPERATURE AND WAVELENGTH DEPENDENT EMISSIVITY

$$V^i_{T_j} = f\,(T_j\,, \varepsilon_i(\lambda,\ T_j))$$

8

OBTAINING M SUCCESSIVE VALUES OF THE OBJECT'S TEMPERATURE $(T_1 \ldots T_j \ldots T_M)$

AND

OBTAINING PARAMETERS OF THE FUNCTION $\varepsilon_i(\lambda,\ T_j)$ FOR EACH SPECTRAL BAND Δ_i

FIG. 2

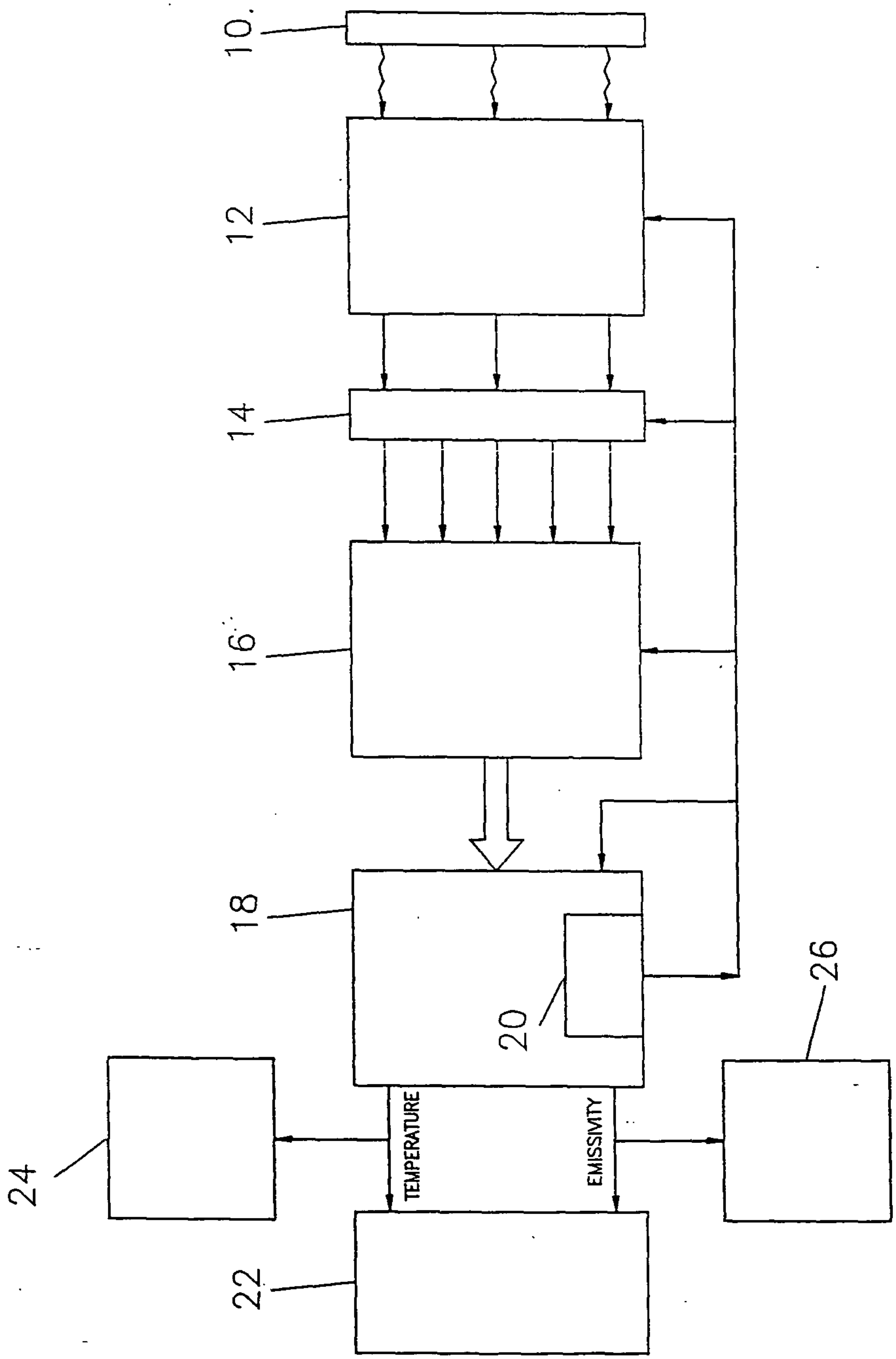

FIG. 3

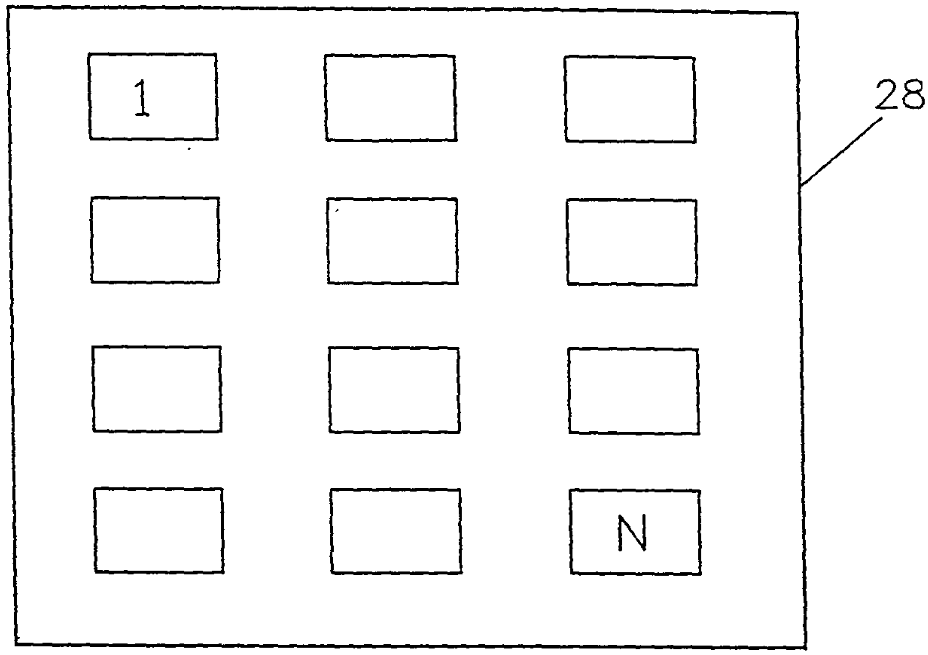

FIG. 4a

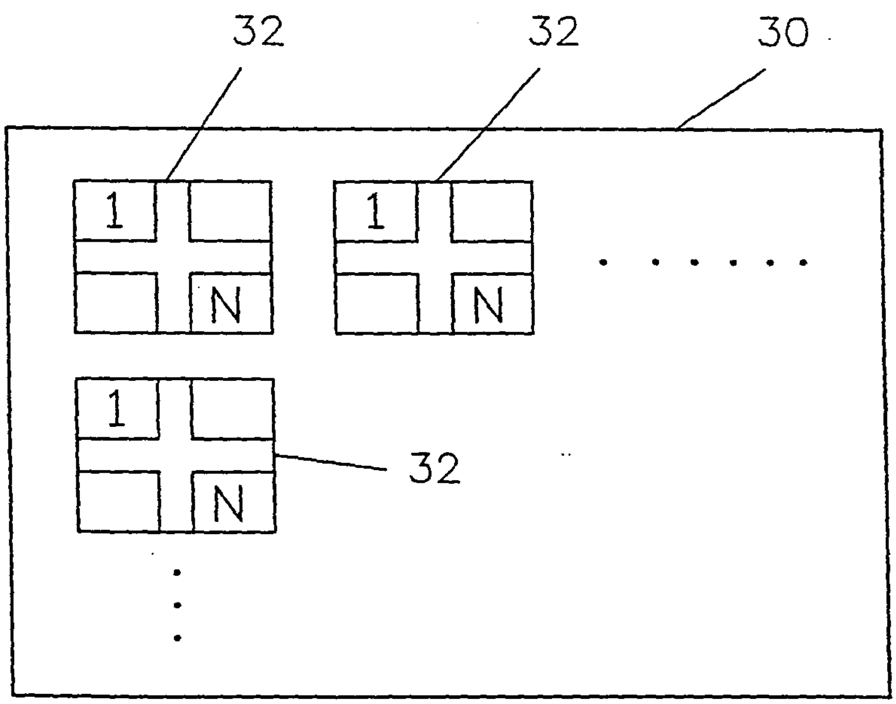

FIG. 4b